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# LONE STAR STEEL STEAM-HYDRO AIR CLEANING SYSTEM EVALUATION

Joseph D. McCain, et al

M. W. Kellog Company

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# LONE STAR STEEL STEAM-HYDRO AIR CLEANING SYSTEM EVALUATION

by

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## ABSTRACT

This report presents the results of fractional and overall mass efficiency tests of the Lone Star Steel Steam-Hydro scrubber. The tests were performed on one of seven modules of a full scale scrubber used for controlling particulate emissions from an open hearth furnace. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 μm to 5 μm, and on a number basis for sizes smaller than about 1 μm using optical and diffusional methods.

The text of this report includes brief descriptions of the open hearth process, the Lone Star Steel steam-hydro scrubber, economics of operating the scrubber, the measurement methods for calculating the fractional efficiency, a synthesized time history of the open hearth particulate emissions, and fractional efficiencies as measured for several scrubber operating conditions.

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# SECTION I
# CONCLUSIONS

The collection efficiency of the Steam-Hydro air cleaning system is quite high. As measured using conventional (Method 5) techniques on a source producing particulate having a mass mean diameter of about 1 μm the efficiency was measured at 99.90 and 99.84% for two days of testing. Measured fractional efficiencies were about 90% at 0.01 μm, about 70% at 0.05 μm, 85% at 0.1 μm, 99.9% at 0.5 μm, 99.99% at 1 μm, and 99.6% at 5 μm. The minimum in the fractional efficiency at about 0.05 μm is probably real, but the actual value is somewhat uncertain because of difficulties in making diffusional measurements in the time variable open hearth process. The manufacturer's estimate of the energy requirements for achieving the efficiencies given above are approximately 8250 BTU/1000 SCF to 12,750 BTU/1000 SCF for system back pressures ranging from one to six inches of water.

## SECTION II

## INTRODUCTION

This report presents results of the tests conducted by Southern Research Institute to determine the capability of the Lone Star Steel Steam-Hydro scrubber to collect fine particulates. The goals of the tests were: (1) to determine optimum operating conditions of the scrubber, (2) to determine the overall mass efficiency and the fractional efficiency of the scrubber while operating under optimum conditions, and (3) to determine the fractional efficiency of the scrubber for some non-optimum operating conditions as time and circumstances permitted. Figure 1 is a schematic of the basic Lone Star Steam-Hydro scrubber showing the inlet and outlet sampling locations.

At the time tests were conducted four of five open hearth furnaces at this plant were operating continuously 24 hours per day. Each furnace producing three 300 ton batches of steel per day with the production time scheduled for each of the four furnaces staggered by about two hours for logistical purposes, although the actual timing for any one furnace varied somewhat from this schedule. The operations for any one batch were: (1) charging of the furnace with scrap metal, requiring about four hours, (2) addition of iron directly from a blast furnace, requiring about thirty minutes, (3) the refining phase (oxygen lance),

requiring about three hours, and finally (4) furnace tapping and pouring, requiring about thirty minutes. The highest sustained particulate emission rates occur during the oxygen lance portion of the operation, with the actual emission rate and size distribution of the particulate being quite variable throughout the cycle. This variability caused some difficulty in both measurement and interpretation of data as is described in the discussion section of this report.

The waste process gases, at temperatures of about 1500°F from the four furnaces, are carried through a series of flues, flow controllers, and ducts to three waste heat boilers, each of which supplies steam to drive seven of the scrubber modules shown in Figure 1. These are arranged in a semi-circle around the boilers. The gas temperature leaving the boilers is about 530°F. The draft for the entire furnace and scrubber system is provided by the steam ejectors in the scrubber modules. Because only three boiler/scrubber systems are used to control the emissions from four furnaces, each system treats the emissions from more than one furnace. The system on which the measurements were made was fed primarily by furnaces 3 and 4 with approximately 67% of the gas handled by the system coming from furnace No. 4. The fact that more than one furnace supplied the system being measured also added to the difficulty in interpreting some of the results and made it impractical to attempt to isolate certain portions of the overall furnace cycle for analysis. The manufacturers description of the operation of the scrubber is given in Appendix A.

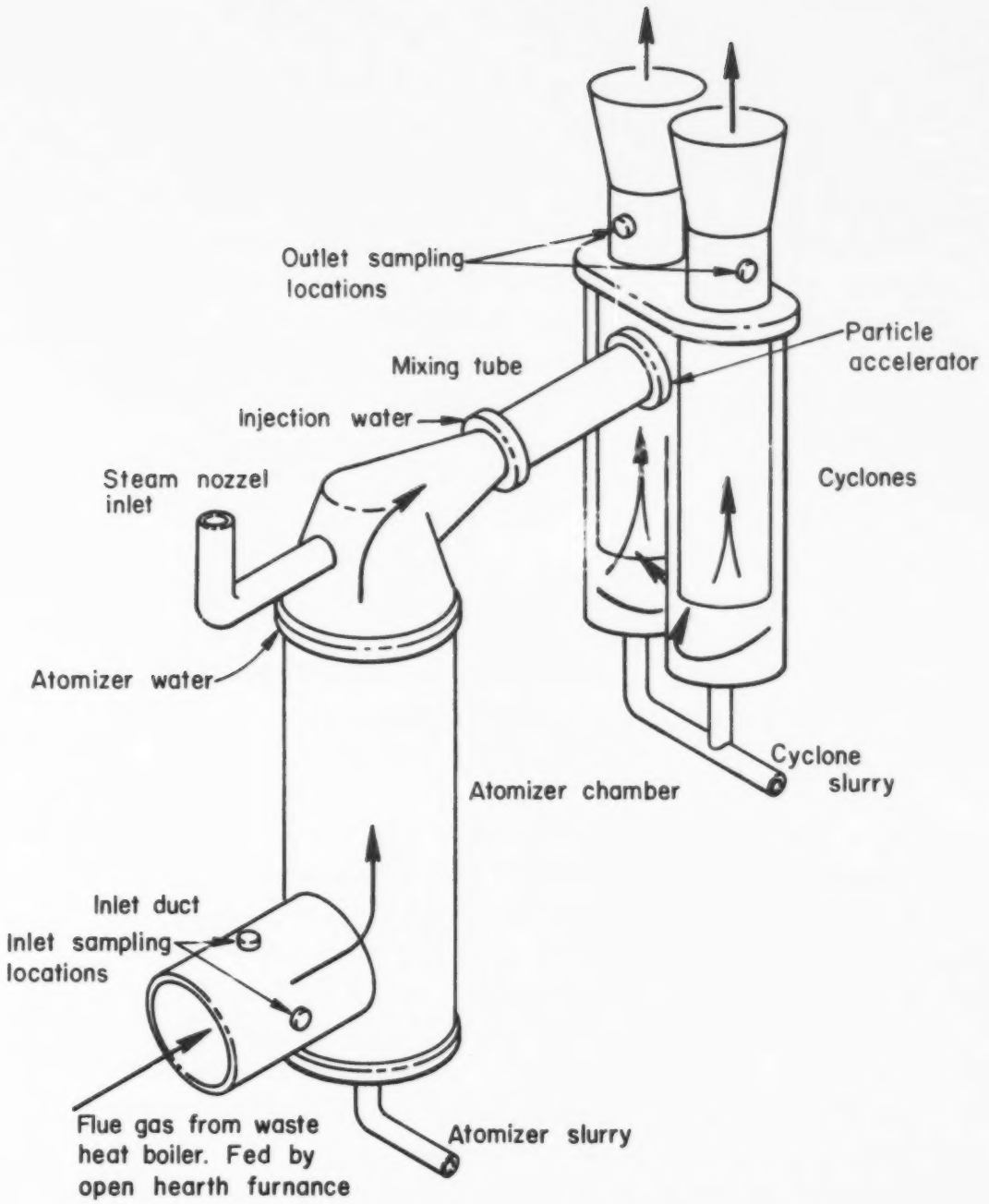


Figure 1. The Lone Star Steel Steam-Hydro Air Cleaning System.

## SECTION III

## DISCUSSION

A total of four measurement techniques were used during the tests. These were: (1) diffusional techniques using condensation nuclei counters and diffusion batteries for determining concentration and size distribution on a number basis for particles having diameters less than approximately 0.2 μm, (2) optical techniques to determine concentrations and size distribution for particles having diameters between approximately 0.3 μm and 1.5 μm, (3) inertial techniques using cascade impactors for determining concentrations and size distributions on a mass basis for particles having diameters between approximately 0.25 μm and 5 μm, and (4) standard mass train measurements for determining total inlet and outlet mass loadings.

The useful concentration ranges of both the optical counter and the condensation nuclei counters are such that extensive dilution of the gas streams being sampled was required. Dilution factors of about 65:1 were used for the outlet measurements and about 500:1 for the inlet measurements. In order to insure that condensation effects were minimal and that the particles were dry as measured, the diluent air was dried and filtered, and diffusional driers were utilized in the lines carrying the diluted samples to the various instruments.

Because of the size and complexity of the optical and diffusional measuring systems, and the fact that only one set of equipment exists for measurements

of this type, it was not possible to obtain simultaneous inlet and outlet data with these methods. The system was first installed at the outlet sampling location, the scrubber was tuned, and all the outlet data were obtained. Subsequently, the equipment was moved to the inlet and the necessary inlet data were obtained. For the purposes of calculating the efficiency of the scrubber, the assumption was made that the open hearth process was sufficiently repetitive that the inlet data, as obtained above, were a valid representation of that which would have been obtained during the time the outlet measurements were made. Accuracy in the diffusional measurements was limited by process variations and the efficiencies derived from these data are rather uncertain. However, the trends in the fractional efficiencies derived from the data are probably real and the fractions of the influent material that penetrate the scrubber are probably correct to within a factor of two to three. Similar tests on a source with less process variations (i.e., a Kraft recovery boiler, or a pulverized coal-fired power boiler) would be desirable in order to refine the efficiency data.

The optical data are presented on the basis of equivalent polystyrene latex sizes and the indicated sizes can differ from the true sizes by factors as large as two to three. Data obtained using this method were primarily intended as a means of real time monitoring of process changes and the results of changes in the scrubber operation, but also serve as rough checks on the data obtained with the cascade

impactors. The sampling system used for obtaining the optical and diffusional data is illustrated diagrammatically in Figure 2.

The tests took place on the dates of December 4 through December 11, 1973, with December 4 primarily used for instrumentation setup, checkout, and preliminary measurements. Optimization of the scrubber operating parameters was accomplished on December 5 using the optical and condensation nuclei counters. The results of these tests are given in Table I , which includes the three primary operating variables (cyclone accelerator position, steam pressure at the ejection nozzle inlet, and gas flow rate). Direct comparisons of data between some of the test conditions are not meaningful because of variations in the open hearth process. This is especially true of tests that are separated by periods of more than a few minutes. The operating condition chosen from the real time optical and CN data did appear to produce lower outlet loadings as later measured with the impactors when compared with two other conditions also used in the tests. The optimum conditions appeared to be accelerator position 3, steam pressure 250 lbs and 11,000 scfm flow rate. Other conditions tested were accelerator position 2, 250 lbs steam pressure and 15,000 scfm; and accelerator position 3, 300 lbs steam pressure, and 13,000 scfm.

Diffusional data for efficiencies below 0.3 $\mu$m were obtained only under the apparent optimum condition. A brief test using the condensation nuclei and

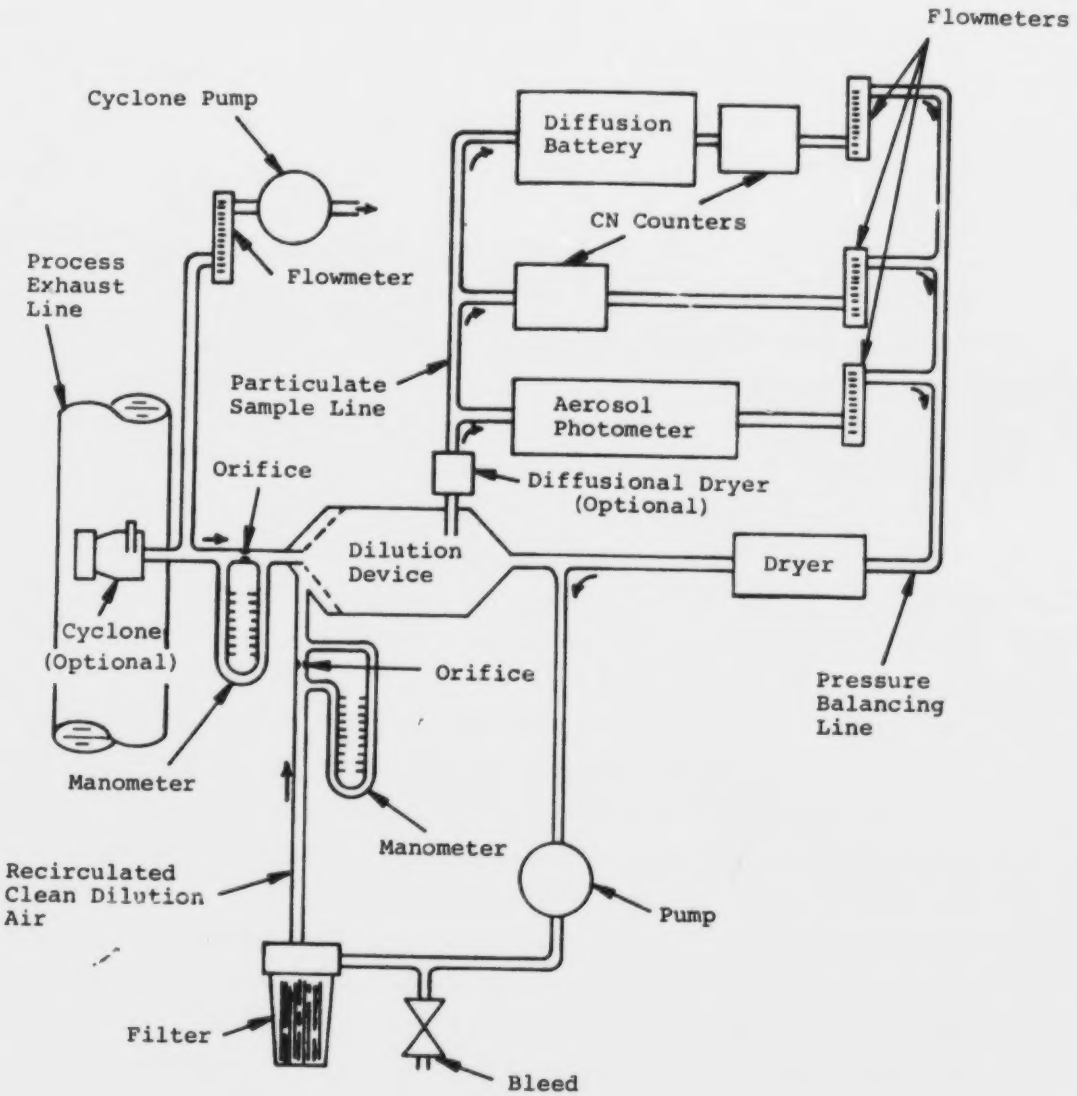


Figure 2. Optical and Diffusional Sizing System.

TABLE I

OPTIMIZATION OF STEAM HYDRO SCRUBBER PERFORMANCE

| Time | Particle Acceleration Position | Steam Pressure psig | Gas Flow lbs/min | Particles/cm³* Dia.≥0.06 μm | Particles/cm³* Dia.≥0.45 μm | Particles/cm³* Dia.≥1.0 μm | Particles/cm³* Dia.≥1.6 μm |
|---|---|---|---|---|---|---|---|
| 1130 | 2 | 250 | 1320 | $0.72 \times 10^6$ | $2.0 \times 10^3$ | 45 | 2 |
| 1140 | 2 | 300 | 1453 | 0.69 | 2.0 | 14 | 2 |
| 1150 | 2 | 350 | 1526 | 0.90 | 2.2 | 200 | 11 |
| 1225 | 1 | 250 | 1404 | 0.94 | > 2.3 | 2100 | 105 |
| 1230 | 1 | 300 | 1498 | 1.51 | > 2.3 | 2400 | 123 |
| 1240 | 1 | 350 | 1581 | 2.24 | > 2.3 | 2400 | 248 |
| 1255 | 0 | 250 | 1510 | 0.93 | > 2.4 | > 2400 | 588 |
| 1300 | 0 | 300 | 1612 | 1.58 | > 2.4 | > 2400 | 235 |
| 1310 | 0 | 350 | 1702 | 1.47 | > 2.4 | 1200 | 214 |
| 1330 | 2 | 250 | 1096 | 0.78 | > 2.2 | 1.6 | 11 |
| 1340 | 2 | 300 | 1182 | 0.78 | > 2.2 | 1.9 | 11 |
| 1730 | 3 | 350 | 1163 | 1.38 | 1.35 | 6.7 | < 2 |
| 1740 | 3 | 300 | 1048 | 1.1 | 1.24 | < 2 | < 2 |
| 1750 | 3 | 250 | 916 | 0.79 | 1.17 | < 2 | < 2 |
| 1800 | 2 | 250 | 1283 | 0.85 | > 2.1 | 15 | < 2 |

* Concentration of particles larger than the stated size in the scrubber effluent gas stream.

optical techniques with the atomizer water turned off indicated a definite increase in the concentration of submicron particles with the atomizer water off. Insufficient data were obtained to fully quantify the effect.

Figures 3 and 4 are recordings made at the outlet using the optical and diffusional systems. Figure 3 is condensation nuclei data which corresponds to particulate concentrations over the range from 0.01 to 0.2 μm in particle diameter. This data was taken over a 25 minute period on December 7, during oxygen lance. It is evident from Figure 3 that even during lance, the most stable process, variations in the particulate concentration are large. Because of this, the accuracy of the diffusional results is limited. For example, when testing, the diffusional system operator may be looking for ten percent changes in concentration due to size related penetration differences in the diffusion batteries, while the open hearth process interjects concentration changes of almost an order of magnitude. In short, the "signal" to "noise" ratio was unfavorable when operating the diffusional system on the open hearth process.

Figure 4 shows optical and diffusional data taken December 7, during a charging cycle. The variations in particulate concentration are quite large, and periodic. The periodicity may be related to the charge operations or to the furnace draft direction

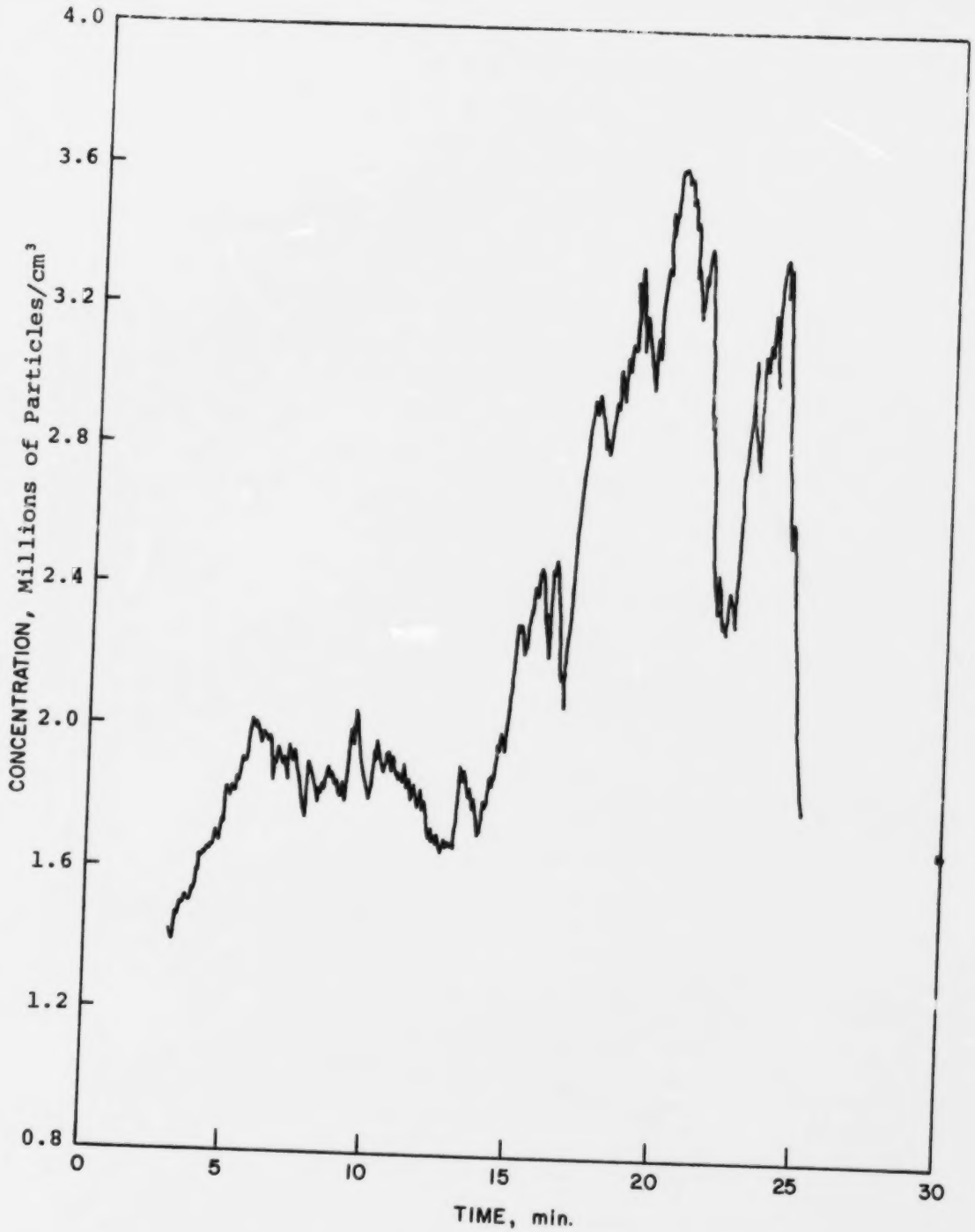


Figure 3. Condensation Nuclei Data Taken During the Oxygen Lance Cycle.

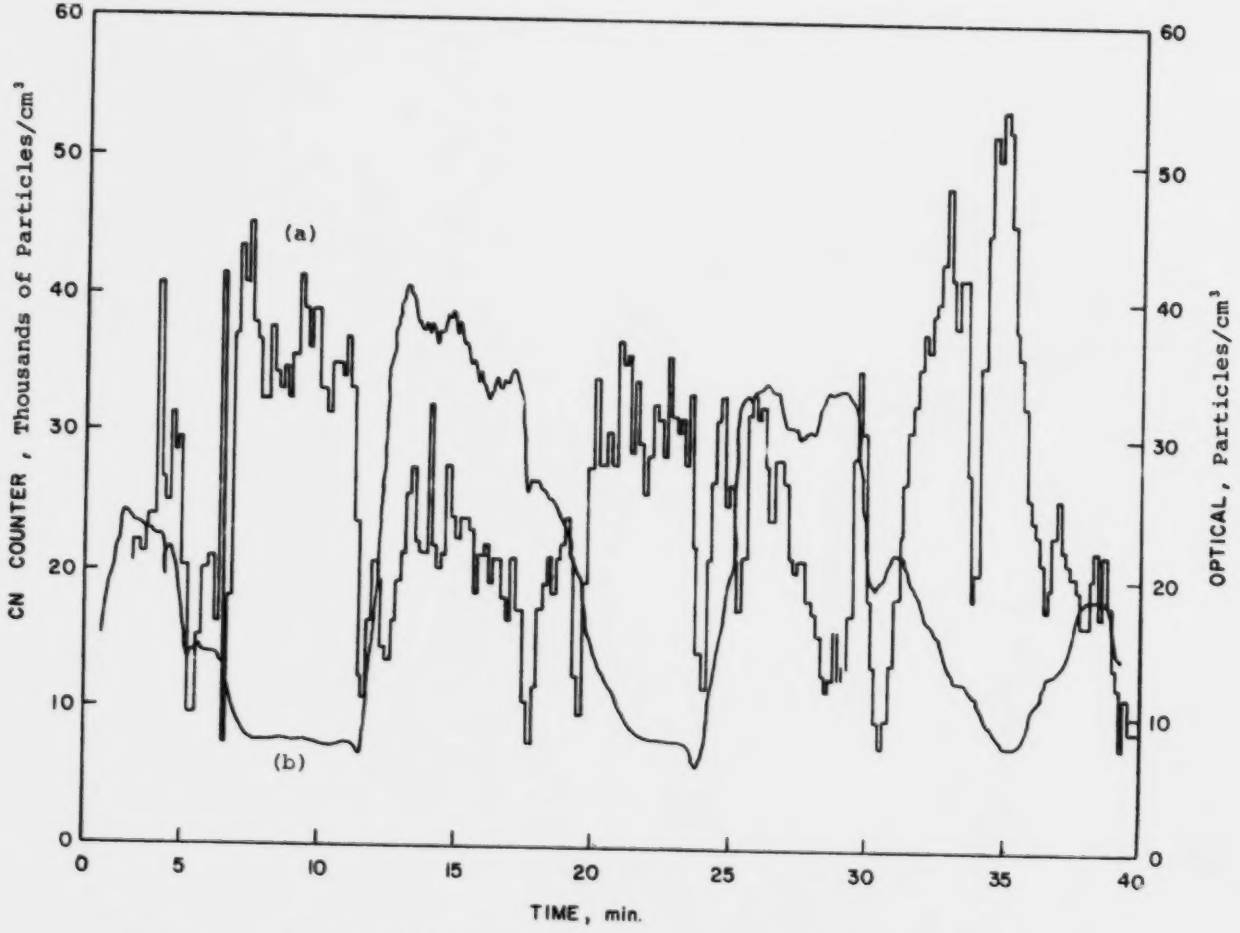


Figure 4. Optical and Condensation Nuclei Counter Data Taken During the Charge Cycle. (a) Optical Data (0.3 - 2 μm Diameter), (b) Diffusional Data (0.01 - 2 μm Diameter). Concentrations are those obtained after dilution by a factor of 1:65.

changes. Curve (a) is optical data and corresponds to the particle concentration from about 0.3 to 2 μm diameter. Curve (b) is condensation nuclei data corresponding to the concentration within the size range from 0.01 to 0.1 μm diameter.

Notice that when the large particle concentration curve (a) increases, the small particle concentration curve (b) decreases. This probably occurs as a result of a higher loss rate by agglomeration resulting from changes in the surface area to which the ultrafine particles may diffuse.

Figure 5 shows typical inlet and outlet size distributions as obtained by optical and diffusional methods during oxygen lance, the most stable process during the heat cycle (see Figure 7). Figure 6 shows the fractional efficiencies calculated from these data together with a set of typical results from the impactor measurements.

Inertial sizing was accomplished using Brink cascade impactors for inlet measurements and Andersen impactors for outlet measurements. Sampling was done at near isokinetic rates. Errors due to deviations from isokinetic sampling should be of little consequence for particles having aerodynamic diameters smaller than 5 μm or physical diameters smaller than 2 μm for an assumed density of 5.2 $gm/cm^3$. Further, because the sampling was at near isokinetic rates, the calculated collection efficiencies for larger particles are

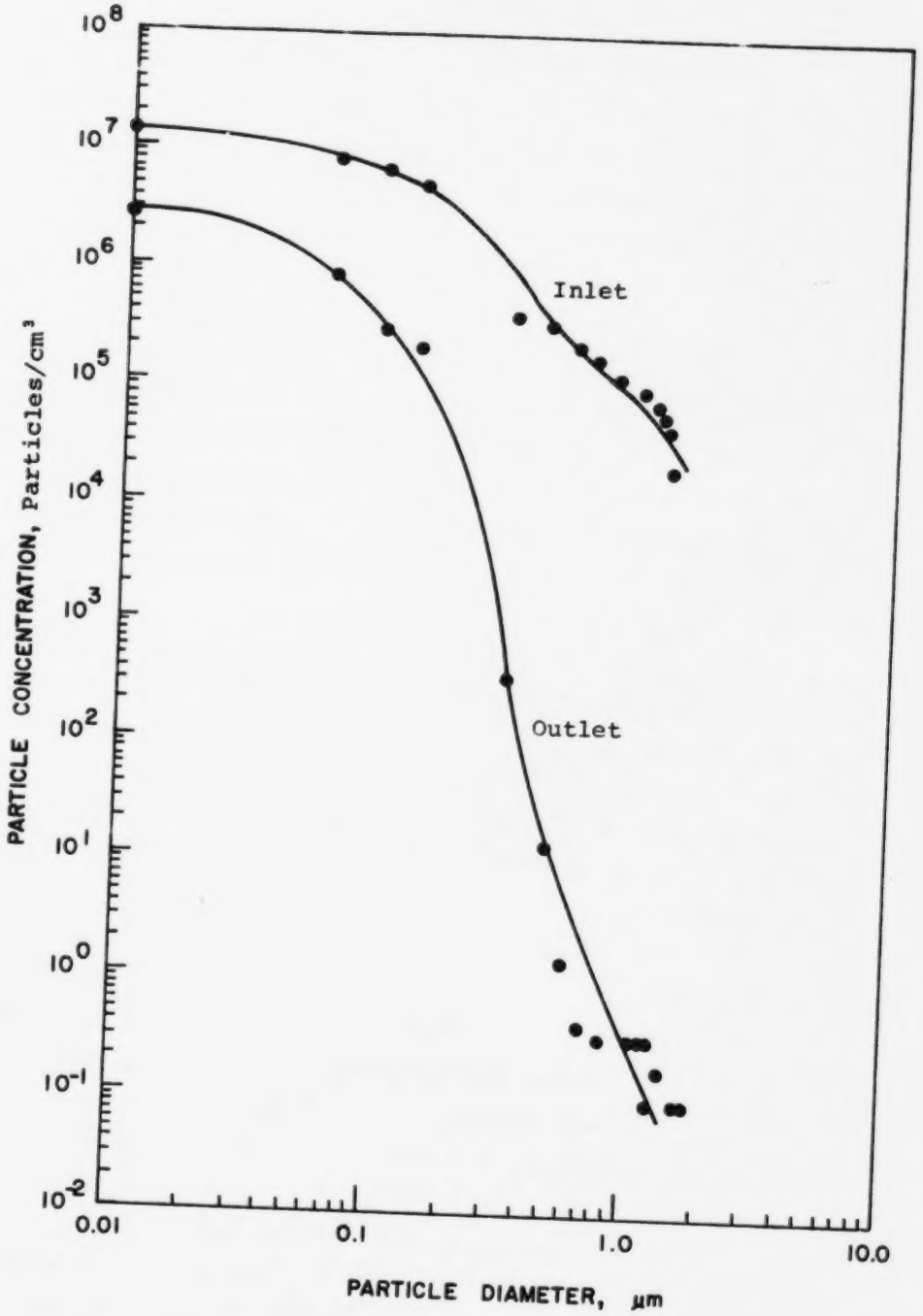


Figure 5. Inlet and Outlet Particle Size Distributions Measured using Optical and Diffusional Techniques.

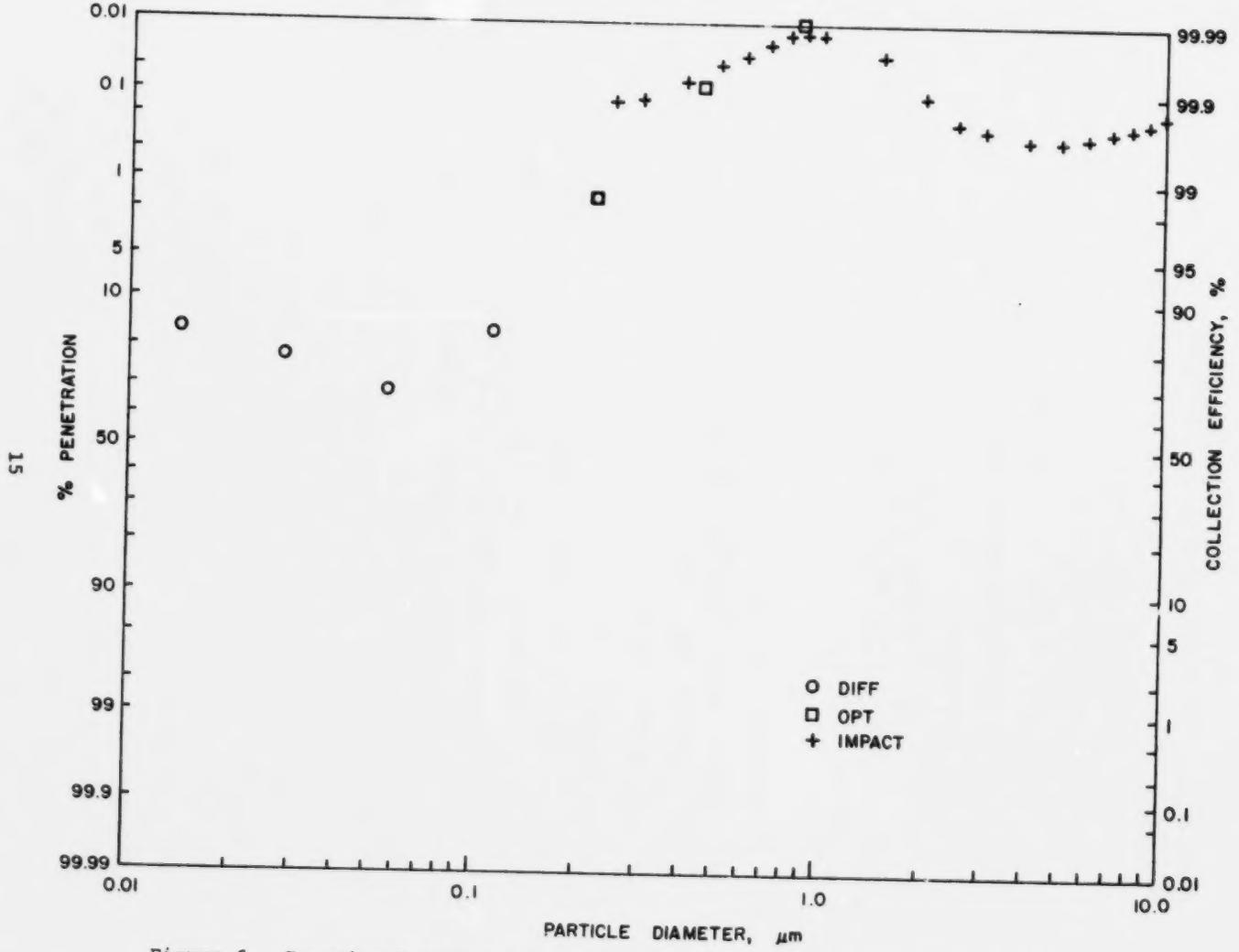


Figure 6. Fractional Efficiency of the Lone Star Steel Steam-Hydro Scrubber.

probably reasonably close to the true values. Because of the relatively small duct dimensions as compared to the sizes of the impactors, single point sampling was used in the ducts with the inlet impactors at flue gas temperature (∿515°F). The outlet impactors were heated to about 40° above flue gas temperature to insure that no condensation took place within the impactor. Such condensation might cause operational difficulties or lead to incorrect sizing.

Because of the wide disparity in the inlet and outlet mass loadings (inlet ∿1 - 2 grains/cf, and outlet ∿0.001 grain/cf) complete simultaneity in the inlet and outlet sampling was not possible. Outlet samples were generally of about 6 hours duration while inlet samples were of about 6 minutes duration. Because of the very low outlet loading and the consequent length of the outlet sampling time, it was found to be impractical to attempt to isolate individual portions of the overall furnace cycle for analysis. A secondary consideration in omitting the furnace operation breakdown in the outlet measurements was the fact that the scrubber was being fed from two furnaces, approximately 67% from number four and 33% from number three, with the phase relations between the two furnace cycles being quite variable. Since the inlet sampling could not correspond directly with the outlet sampling, an inlet mass loading history for one complete furnace cycle was synthesized for each size interval covered by the inlet impaction stages. Examples of these synthesized histories are shown in Figure 7.

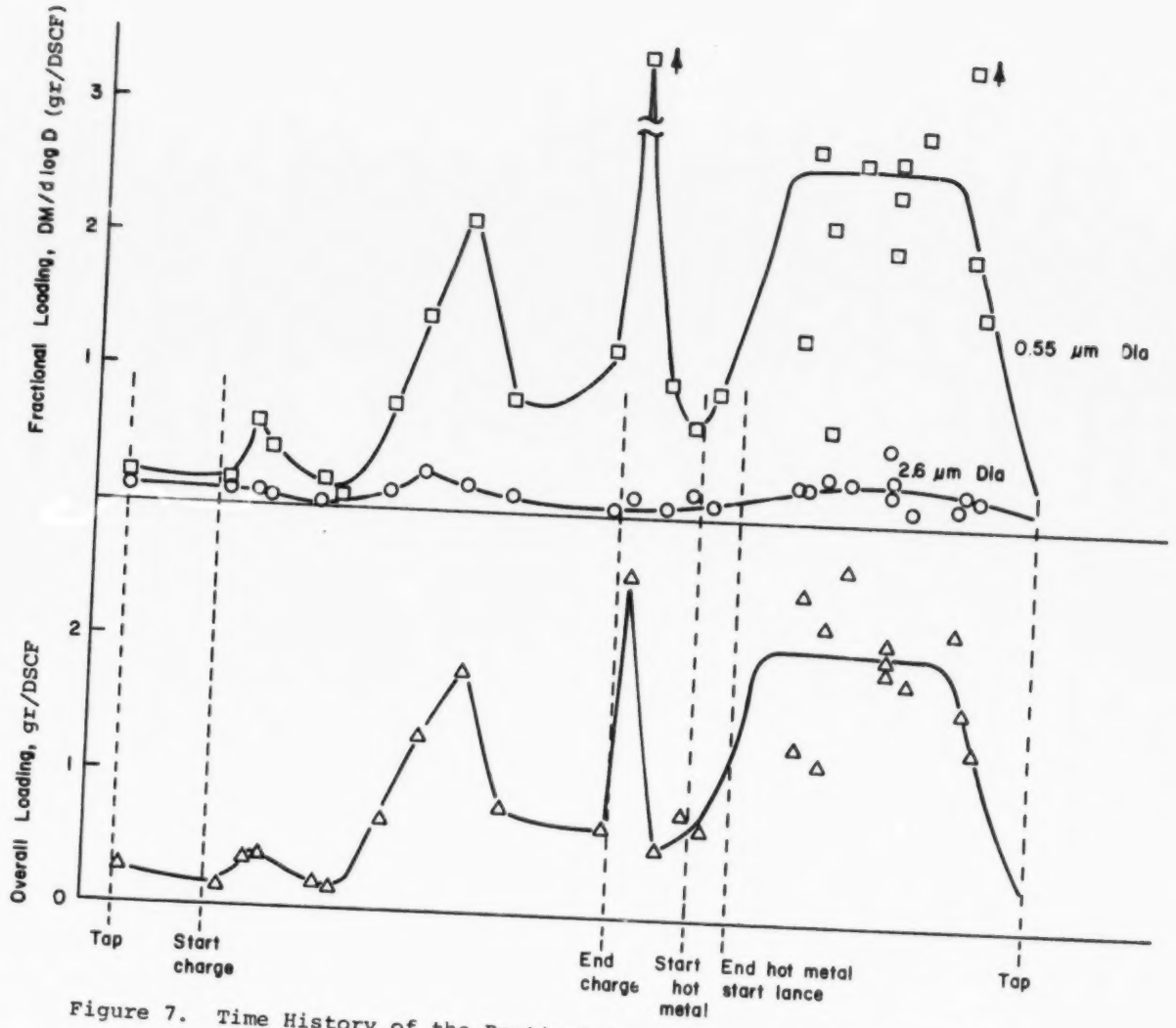


Figure 7. Time History of the Particulate Loading at the Inlet of the Steam-Hydro Scrubber. The Time Period Shown is About Eight Hours.

Appropriate time averages from the synthesized complete cycle was used in computing the fractional efficiencies from the impactor data.

The sizes reported here for the inertial data are based on an assumed particle density of 5.2 gm/cm$^3$. If the true particle densities are lower than this value, the sizes as given should be increased by a factor equal to the square root of ratio of the assumed density to true density. The impactor data are summarized in Tables II and III and the fractional efficiencies as calculated from these data are shown in Figure 8.

Mass train measurements were obtained by Guardian Systems, Inc., of Anniston, Alabama, under subcontract to Southern Research Institute on December 10 and 11, and the results of these measurements are shown in Tables IV and V. The overall efficiencies, by mass, based on these results are included in Table V.

Appendices are included which contain summaries of furnace and scrubber operations during the time intervals over which data were obtained, and cost-estimates for the operation of the scrubber.

With regard to the scrubber energy requirements, it should be noted that the steam flow is that which is required to pump and clean a gas stream with approximately five to seven inches of water back pressure. According to the manufacturer, the amount of steam used is a function of this back pressure.

TABLE II

SCRUBBER OUTLET LOADING BY SIZE INTERVAL

| DATE(S) & TIME(S) | 12/6 12:03/ 13:33 | 12/6 17:45/ 19:15 12/7 11:45/ 13:32 | 12/7* 10:03/ 11:33 13:35/ 14:00 | 12/8 10:30/ 16:30 | 12/9 09:30/ 10:25 10:55/ 16:00 | 12/10 10:15/ 19:15 | 12/11 09:45/ 16:10 |
|---|---|---|---|---|---|---|---|
| Acc. Position | 3 | 3 | 3 | 3 | 2 | 3 | 3 |
| Steam Pres. | 250 | 250 | 250 | 300 | 250 | 300 | 300 |
| Scrubber Flow Rate | 11,000 | 11,000 | 11,000 | 13,000 | 15,000 | 13,000 | 13,000 |
| #4 Furnace Operations During Measurement | Lance | Lance | Non-Lance | 60% NL 40% L | 60% NL 40% L | 60% Lance 40% NL | 60% Lance 40% NL |
| Overall Loading (gr/dscf) | 0.0012 | 0.0012 | 0.0014 | 0.00086 | 0.0016 | 0.00009 | 0.0017 |
| Size Interval/Loading Microns/(gr/dscf) | | | | | | | |
| >6.04 | 0.00009 | 0.00013 | | | 0.00007 | 0.00004 | 0.00015 |
| 3.75-6.04 | 0.00002 | 0.00005 | | | 0.00006 | 0.00004 | 0.00010 |
| 2.53-3.75 | 0.00000 | 0.00006 | | | 0.00004 | 0.00004 | 0.00009 |
| 1.71-2.53 | 0.00008 | 0.00004 | | | 0.00003 | 0.00002 | 0.00012 |
| 1.09-1.71 | 0.00001 | 0.00001 | | 0.00003** | 0.00002 | 0.00002 | 0.00009 |
| 0.52-1.09 | 0.00008 | 0.00007 | | 0.00007 | 0.00006 | 0.00005 | 0.00012 |
| 0.30-0.52 | 0.00018 | 0.00015 | 0.00040** | 0.00014 | 0.00016 | 0.00014 | 0.00023 |
| 0.18-0.30 | 0.00017 | 0.00017 | 0.00018 | 0.00012 | 0.00020 | 0.00011 | 0.00017 |
| <0.18 | 0.00053 | 0.00052 | 0.00081 | 0.00049 | 0.00091 | 0.00042 | 0.00060 |

* Heater failed resulting in large amount of water condensing in impactor.

** Value represents the total loading for all particle sizes larger than the minimum size shown for this impactor stage. All impactor stages were not used for these runs.

TABLE III

SCRUBBER INLET LOADING BY SIZE INTERVAL *

| Date | Time | #4 Oper. | Time After Op. Start. | Total Load | Dia. (ρ=5.2 | Loading in Size Interval, grains/sdcf | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | >6.0 | >3.4 | 3.4-6.0 | 2.0-3.4 | 1.3-2.0 | 0.70-1.3 | 0.43-0.70 | 0.23-0.43 | <0.43 | <0.23) |
| 12/11 | 10:23 | Charge | 3 | 0.157 | | 0.024 | | 0.021 | 0.029 | 0.012 | 0.021 | 0.036 | | 0.014 | |
| 12/09 | 13:07 | | 10 | 0.346 | | 0.064 | | 0.005 | 0.016 | 0.029 | 0.096 | 0.128 | | 0.007 | |
| 12/07 | 14:44 | | 15 | 0.385 | | | 0.048 | | 0.013 | 0.018 | 0.084 | 0.088 | 0.100 | | 0.033 |
| 12/08 | 15:03 | | 35 | 0.182 | | 0.029 | | 0.008 | 0.003 | 0.014 | 0.020 | 0.043 | | 0.065 | |
| 12/05 | 15:00 | | 40 | 0.129 | | | 0.048 | | 0.017 | 0.008 | 0.005 | 0.013 | 0.029 | | 0.008 |
| 12/08 | 09:48 | | 60 | 0.656 | | 0.088 | | 0.010 | 0.027 | 0.057 | 0.207 | 0.158 | | 0.110 | |
| 12/11 | 11:33 | | 75 | 1.29 | | | 0.250 | | 0.062 | 0.045 | 0.210 | 0.312 | 0.319 | | 0.091 |
| 12/08 | 16:01 | | 90 | 1.81 | | | 0.299 | | 0.042 | 0.123 | 0.290 | 0.459 | 0.471 | | 0.123 |
| 12/05 | 15:57 | | 100 | 0.784 | | 0.176 | | 0.010 | 0.027 | 0.080 | 0.225 | 0.171 | | 0.094 | |
| 12/10 | 16:12 | | 160 | 0.656 | | 0.075 | | 0.000 | 0.002 | 0.016 | 0.152 | 0.252 | | 0.159 | |
| 12/07 | 10:46 | | 180 | 2.55 | | | 0.109 | | 0.028 | 0.139 | 0.430 | 1.066 | 0.735 | | 0.049 |
| | | End of Charge to Hot | | | | | | | | | | | | | |
| 12/09 | 09:54 | Metal | 15 | 0.507 | | 0.063 | | 0.006 | 0.009 | 0.035 | 0.118 | 0.205 | | 0.070 | |
| 12/08 | 11:45 | | 45 | 0.768 | | | 0.203 | | 0.038 | 0.070 | 0.161 | 0.142 | 0.125 | | 0.029 |
| 12/09 | 16:10 | Hot Metal | 0 | 0.616 | | | 0.077 | | 0.019 | 0.014 | 0.112 | 0.197 | 0.149 | | 0.048 |
| 12/11 | 13:34 | Lance | 19 | 1.30 | | 0.238 | | 0.048 | 0.057 | 0.152 | 0.403 | 0.274 | | 0.125 | |
| 12/06 | 17:52 | | 22 | 2.46 | | | 0.230 | | 0.060 | 0.218 | 0.797 | 0.589 | 0.356 | | 0.214 |
| 12/06 | 12:18 | | 30 | 2.20 | | | 0.346 | | 0.066 | 0.180 | 0.678 | 0.469 | 0.273 | | 0.188 |
| 12/07 | 11:57 | | 30 | 1.18 | | 0.337 | | 0.035 | 0.079 | 0.266 | 0.206 | 0.141 | | 0.156 | |
| 12/05 | 11:46 | | 40 | 2.63 | | | 0.444 | | 0.068 | 0.230 | 0.866 | 0.569 | 0.205 | | 0.251 |
| 12/05 | 11:55 | | 50 | 2.11 | | 0.472 | | 0.050 | 0.127 | 0.196 | 0.679 | 0.425 | | 0.156 | |
| 12/09 | 11:13 | | 55 | 1.87 | | | 0.433 | | 0.052 | 0.138 | 0.379 | 0.527 | 0.304 | | 0.042 |
| 12/10 | 18:15 | | 55 | 2.02 | | | 0.134 | | 0.075 | 0.170 | 0.622 | 0.572 | 0.248 | | 0.200 |
| 12/10 | 11:38 | | 63 | 1.82 | | 0.148 | | 0.009 | 0.022 | 0.031 | 0.390 | 0.612 | | 0.605 | |
| 12/06 | 18:49 | | 80 | 2.18 | | 0.154 | | 0.029 | 0.032 | 0.050 | 0.202 | 0.967 | | 0.747 | |
| 12/11 | 14:37 | | 82 | 1.61 | | | 0.274 | | 0.059 | 0.143 | 0.367 | 0.428 | 0.256 | | 0.082 |
| 12/06 | 13:16 | | 86 | 1.32 | | 0.209 | | 0.031 | 0.047 | 0.209 | 0.205 | 0.324 | | 0.294 | |
| 12/10 | 12:32 | Tap | 7 | 0.267 | | | 0.113 | | 0.022 | 0.006 | 0.012 | 0.041 | 0.056 | | 0.016 |
| | | | | | (Dia. (ρ=1. | >14 | >7.9 | 7.9-14 | 4.7-7.9 | 3.2-4.7 | 1.8-3.2 | 1.1-1.8 | 0.69-1.1 | | <0.69) |

* Samples are ordered to synthesize one complete furnace cycle.

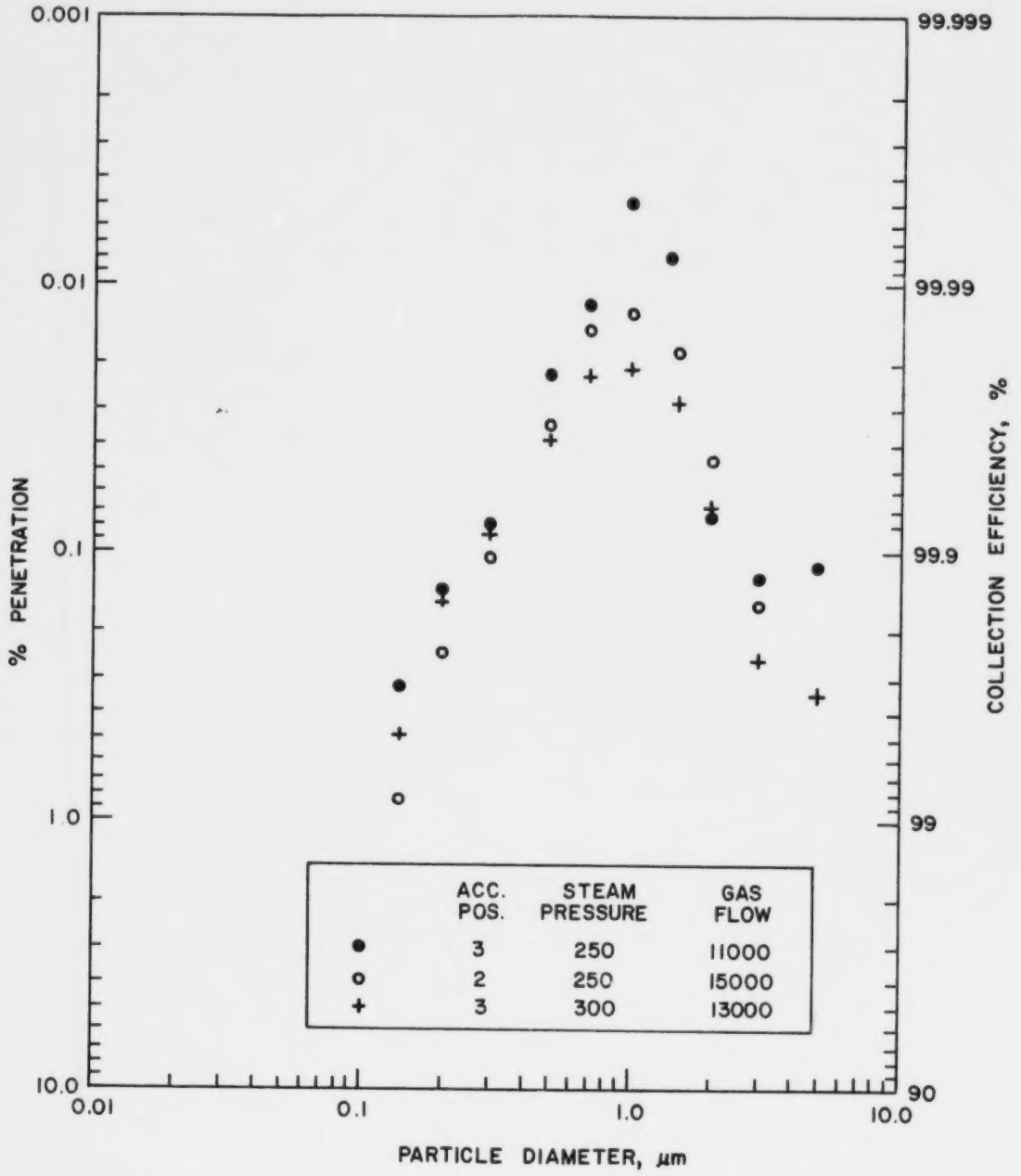


Figure 8. Fractional Efficiency Calculated Using Impactor Data Only.

TABLE IV

MASS TRAIN TEST RESULTS
Lone Star Steel
Steam-Hydro Air Cleaning System

| Position: | Inlet | Inlet | Inlet | Inlet | Inlet | Inlet |
|---|---|---|---|---|---|---|
| Date: | 12/10 | 12/10 | 12/10 | 12/10 | 12/11 | 12/11 |
| Test No.: | 1 | 2 | 3 | 4 | 1 | 2 |
| Stack Temp: °R | 965 | 965 | 970 | 965 | 995 | 995 |
| Moisture, % | 5.42 | 4.68 | 8.50 | 4.04 | 3.63 | 3.44 |
| Avg. Velocity, fpm | 1428 | 1613 | 1780 | 1835 | 1398 | 1718 |
| Flow, ACFM | 17939 | 20261 | 22350 | 23047 | 17561 | 21582 |
| Flow, DSCFM | 9110 | 10476 | 11036 | 11996 | 8849 | 10940 |
| Grains/ACF | 0.306 | 0.132 | 0.259 | 0.627 | 0.157 | 0.467 |
| Grains/DSCF | 0.597 | 0.255 | 0.525 | 1.205 | 0.312 | 0.921 |
| Run Duration (min) | 60 | 120 | 40 | 120 | 160 | 165 |
| Time: | 11:15 | 12:35 | 15:30 | 17:15 | 09:00 | 13:20 |

TABLE V

MASS TRAIN TEST RESULTS
Lone Star Steel
Steam-Hydro Air Cleaning System

| Position: | Outlet | Outlet | Outlet | Outlet | Outlet | Outlet | Outlet | Outlet | Outlet |
|---|---|---|---|---|---|---|---|---|---|
| Date: | 12/10 | 12/10 | 12/10 | 12/10 | 12/11 | 12/11 | 12/11 | 12/11 | 12/11 |
| Time: | 11:30 | 13:00 | 15:00 | 17:00 | 09:00 | 10:30 | 12:00 | 13:30 | 15:00 |
| Test No.: | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 |
| Stack Temp.:°R | 620 | 623 | 621 | 621 | 624 | 622 | 624 | 625 | 625 |
| Moisture, % | 29.31 | 34.21 | 28.78 | 20.71 | 29.21 | 33.00 | 36.44 | 38.44 | 34.43 |
| Grains/ACF | 0.0002 | 0.0003 | 0.0003 | 0.0006 | 0.0004 | 0.0004 | 0.0004 | 0.0004 | 0.0004 |
| Grains/DSCF | 0.0003 | 0.0005 | 0.0005 | 0.0008 | 0.0007 | 0.0007 | 0.0007 | 0.0007 | 0.0007 |
| Run Duration (min) | 70 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Scrubber Eff. | 99.95 | 99.80 | 99.90 | 99.93 | 99.78 | 99.78 | 99.78 | 99.92 | 99.92 |

For example, the amount of steam required to pump and clean a system with two inches of water back pressure is approximately one third that required at five to seven inches. (Excessive back pressure is caused in the case of the Lone Star Steel system by dirty waste heat boilers).

## SECTION IV

## APPENDICES

A MANUFACTURER'S DESCRIPTION OF THE OPERATION OF THE SCRUBBER

B SCRUBBER OPERATING PARAMETERS DURING TESTS

$C^1$ OPEN HEARTH FURNACE OPERATING SUMMARY

$C^2$ OPEN HEARTH FURNACE MATERIALS SUMMARY

D ESTIMATED OPERATING COSTS OF THE STEAM HYDRO AIR CLEANING SYSTEM

E CONVERSION FACTORS

## APPENDIX A

## MANUFACTURER'S DESCRIPTION OF THE OPERATION OF THE SCRUBBER

The system utilizes a high-speed steam drive with injected water to perform an extremely efficient scrubbing action. The heart of the system, which contains no moving parts, consists of a steam nozzle, water injector, mixing tube and twin cyclones. System operation is simple and easily controlled.

Normally, the system operates on energy produced by waste heat captured from the process being controlled. The heat is used to generate steam in a waste heat boiler. In installations where heat energy is low, supplemental heat may be provided. In many cases, a package steam boiler may supply all the energy.

In addition to driving the system, the steam nozzle creates draft which draws contaminated gases into the system.

### Atomizer Chamber

First stage of cleaning is done in an optional atomizing chamber with water sprays that may be employed to cool the gas stream and remove heavy particulate. Most processes do not require this chamber but it can be installed as a first-phase cleaner for certain difficult effluents. A negative pressure is

maintained in this chamber. A process occurs where steam joins small particulate for second-phase removal in the mixing tube.

Mixing Tube

Collision between injected water droplets and the particulate, (including acidic gases if present) encapsulation, nucleation, and droplet growth take place in the mixing tube. Collisions occur between particulate and billions of high-speed water droplets. Particulate is encapsulated and a growth process begins to bring submicron particulate to manageable size for disposal through low-pressure-drop cyclones. To insure positive capture of all particulate, a shock wave pattern is created in the mixing tube. Massive turbulence created by the shock wave pattern subjects encapsulated particulate to a sudden and violent scrubbing action.

Cyclones

Separation of particulate from the gas is achieved by entering low-pressure-drop cyclones with appropriate velocities and particulate which has grown to a size matched to the system. Centrifugal energy in the cyclones is maintained by force imparted from the mixing tube.

APPENDIX B

SCRUBBER OPERATING PARAMETERS DURING TESTS

| Date | 24 Hour Time | Furnace | Condition | Steam Flow Lbs/hr. | Gas Flow SCFM | Injection Water GPM | Atomizer Water GPM | Atomizer Slurry GPM | Cyclone Slurry GPM | Particle Accrl. Position | Nozzle Steam Pres. psig | Steam Temp. °F | Emission GR/SCF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12/05/73 | 11:05-13:40 | 4 | Lance | 8379 | 18,441 | 30 | 27.2 | 23.3 | 29.8 | Varied 1-3 | Varied 250-350 | 590-620 | |
| | 12:20-12:35 | 3 | Hot Metal | 7851 | 18,449 | 30 | 27.6 | 22.2 | 30.7 | 1-3 | 250-350 | 590-620 | |
| | 12:35-13:40 | 3 | Lance | 8519 | 18,562 | 30 | 27.5 | 24.4 | 28.4 | 1-3 | 250-350 | 590-620 | |
| | 17:30-18:33 | 4 | Lance | 8108 | 14,362 | 31.5 | 25.7 | 26.9 | 28.3 | 1-3 | 250-350 | 590-620 | |
| | 17:30-18:15 | 3 | Charge | 7932 | 13,887 | 31.6 | 26.1 | 27.4 | 28.5 | 1-3 | 250-350 | 590-620 | |
| 12/06/73 | 12:00-13:41 | 4 | Lance | 7357 | 10,926 | 33.6 | 26.2 | 23.7 | 28.1 | 03 | 250 | 545 | 0.0012 |
| | 12:20-12:35 | 3 | Hot Metal | 7357 | 11,116 | 33.6 | 26.2 | 23.5 | 28.1 | 03 | 250 | 545 | 0.0012 |
| | 12:35-14:50 | 3 | Charge | 7357 | 10,741 | 33.6 | 26.2 | 23.9 | 28.1 | 03 | 250 | 545 | 0.0012 |
| | 14:20-16:20 | 4 | Charge | 7357 | 10,659 | 33.6 | 24.6 | 23.9 | 28.1 | 03 | 250 | 545 | 0.0012 |
| | 15:05-15:15 | 3 | Hot Metal | 7357 | 10,674 | 33.6 | 24.3 | 23.9 | 28.1 | 03 | 250 | 545 | 0.0012 |
| | 15:15-17:25 | 3 | Lance | 7357 | 10,761 | 33.6 | 23.6 | 24.1 | 28.6 | 03 | 250 | 545 | 0.0012 |
| | 17:15-17:30 | 4 | Hot Metal | 7357 | 11,065 | 33.1 | 0 | 0 | 24.1 | 03 | 250 | 545 | 0.0012 |
| | 17:30-19:30 | 4 | Lance | 7560 | 10,782 | 32.6 | 26.4 | 23.9 | 28.8 | 03 | 250 | 545 | 0.0012 |
| | 18:05-19:30 | 3 | Charge | 7560 | 10,782 | 32.6 | 26.4 | 23.9 | 28.8 | 03 | 250 | 545 | 0.0012 |
| 12/07/73 | 09:00-10:09 | 3 | Lance | 7270 | 10,937 | 33.6 | 25.9 | 23.6 | 30.1 | 03 | 250 | 550 | 0.0012 |
| | 09:00-10:50 | 4 | Charge | 7270 | 10,919 | 33.2 | 25.9 | 23.6 | 29.6 | 03 | 250 | 550 | 0.0012 |
| | 10:50-12:45 | 3 | Charge | 7357 | 10,722 | 32.7 | 26.3 | 24.4 | 27.6 | 03 | 250 | 550 | 0.0012 |
| | 11:15-11:30 | 4 | Hot Metal | 7357 | 10,638 | 32.6 | 26.6 | 25.6 | 28.1 | 03 | 250 | 550 | 0.0012 |
| | 11:30-13:05 | 4 | Lance | 7386 | 10,770 | 32.7 | 26.1 | 23.8 | 28.1 | 03 | 250 | 550 | 0.0012 |
| | 13:25-13:55 | 3 | Hot Metal | 7328 | 10,817 | 33.1 | 26.0 | 25.7 | 27.4 | 03 | 250 | 550 | 0.0012 |
| | 13:55-15:38 | 3 | Lance | 7299 | 10,954 | 32.6 | 26.3 | 25.8 | 28.5 | 03 | 250 | 550 | 0.0012 |
| | 14:30-15:38 | 4 | Lance | 7328 | 10,949 | 32.6 | 26.4 | 25.9 | 28.6 | 03 | 250 | 550 | 0.0012 |
| 12/08/73 | 10:30-11:00 | 4 | Charge | 8695 | 12,999 | 33.4 | 26.0 | 23.0 | 31.4 | 03 | 300 | 560 | 0.00082 |
| | 11:05-12:55 | 3 | Charge | 8840 | 12,933 | 33.5 | 26.0 | 22.6 | 31.3 | 03 | 300 | 560 | 0.00082 |
| | 12:10-12:25 | 4 | Hot Metal | 9202 | 12,904 | 33.6 | 25.9 | 22.4 | 31.3 | 03 | 300 | 560 | 0.00082 |
| | 12:25-13:50 | 4 | Lance | 8811 | 13,036 | 33.6 | 25.8 | 22.5 | 31.6 | 03 | 300 | 560 | 0.00082 |
| | 13:30-13:45 | 3 | Hot Metal | 8695 | 13,200 | 33.6 | 25.8 | 23.3 | 31.6 | 03 | 300 | 560 | 0.00082 |
| | 13:45-15:40 | 3 | Lance | 8724 | 13,011 | 33.6 | 25.9 | 22.3 | 31.5 | 03 | 300 | 560 | 0.00082 |
| | 14:30-16:30 | 4 | Charge | 8666 | 12,967 | 33.4 | 25.9 | 22.2 | 31.4 | 03 | 300 | 560 | 0.00082 |

*Time intervals are shown to cover the individual furnace operation of furnaces 3 and 4.

APPENDIX B
(Continued)

| Date | 24 Hour Time | Furnace | Condition | Steam Flow Lbs/hr. | Gas Flow SCFM | Injection Water GPM | Atomizer Water GPM | Atomizer Slurry GPM | Cyclone Slurry GPM | Particle Accrl. Position | Nozzle Steam Pres. psig | Steam Temp. °F | Emission GR/SCF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12/09/73 | 08:30-09:40 | 3 | Lance | 7287 | 15,094 | 35.5 | 25.9 | 22.5 | 32.5 | 02 | 250 | 540 | 0.0015 |
| | 08:30-09:40 | 4 | Charge | 7287 | 15,094 | 35.5 | 25.9 | 22.5 | 32.5 | 02 | 250 | 540 | 0.0015 |
| | 10:05-10:20 | 4 | Hot Metal | 7299 | 15,146 | 35.5 | 25.6 | 24.0 | 32.0 | 02 | 250 | 540 | 0.0015 |
| | 10:20-12:20 | 4 | Lance | 7317 | 15,022 | 35.6 | 24.9 | 22.7 | 32.0 | 02 | 250 | 540 | 0.0015 |
| | 10:20-12:40 | 3 | Charge | 7317 | 15,059 | 35.6 | 24.9 | 22.6 | 32.1 | 02 | 250 | 540 | 0.0015 |
| | 12:40-13:10 | 3 | Hot Metal | 7328 | 15,020 | 35.0 | 24.7 | 21.7 | 33.5 | 02 | 250 | 540 | 0.0015 |
| | 13:00-15:35 | 4 | Charge | 7328 | 14,996 | 35.0 | 24.8 | 21.5 | 33.7 | 02 | 250 | 540 | 0.0015 |
| | 13:20-15:35 | 3 | Lance | 7320 | 15,065 | 35.1 | 24.8 | 21.5 | 33.7 | 02 | 250 | 540 | 0.0015 |
| | 16:10-16:25 | 4 | Hot Metal | 7386 | 14,933 | 35.0 | 24.5 | 19.9 | 34.8 | 02 | 250 | 540 | 0.0015 |
| | 16:20-16:30* | 3 | Charge | 7386 | 14,933 | 35.0 | 24.5 | 19.9 | 34.8 | 02 | 250 | 540 | 0.0015 |
| | 16:25-16:30* | 4 | Lance | 7386 | 14,933 | 35.0 | 24.5 | 19.9 | 34.8 | 02 | 250 | 540 | 0.0015 |
| 12/10/73 | 09:00-09:30 | 4 | Charge | 8834 | 12,834 | 34.6 | 25.9 | 21.9 | 33.4 | 03 | 300 | 555 | 0.00089 |
| | 09:00-11:04 | 3 | Lance | 8753 | 13,042 | 34.4 | 26.6 | 23.1 | 32.7 | 03 | 300 | 555 | 0.00089 |
| | 10:20-10:35 | 4 | Hot Metal | 8561 | 13,149 | 34.1 | 27.3 | 24.9 | 32.4 | 03 | 300 | 555 | 0.00089 |
| | 10:35-12:25 | 4 | Lance | 8666 | 13,060 | 34.1 | 26.8 | 23.5 | 32.3 | 03 | 300 | 555 | 0.00089 |
| | 11:45-13:45 | 3 | Charge | 8753 | 13,021 | 34.1 | 26.7 | 23.0 | 32.0 | 03 | 300 | 555 | 0.00089 |
| | 13:30-16:25 | 4 | Charge | 8736 | 12,985 | 33.7 | 26.7 | 22.6 | 32.2 | 03 | 300 | 555 | 0.00089 |
| | 14:30-14:45 | 3 | Hot Metal | 8724 | 13,088 | 33.6 | 27.1 | 22.3 | 32.2 | 03 | 300 | 555 | 0.00089 |
| | 14:45-16:40 | 3 | Lance | 8753 | 13,064 | 33.6 | 26.7 | 22.5 | 32.3 | 03 | 300 | 555 | 0.00089 |
| | 17:00-17:20 | 4 | Hot Metal | 8637 | 13,355 | 34.1 | 26.6 | 23.1 | 32.9 | 03 | 300 | 555 | 0.00089 |
| | 17:20-19:10 | 4 | Lance | 8637 | 12,909 | 33.0 | 26.5 | 22.7 | 32.1 | 03 | 300 | 555 | 0.00089 |
| | 17:20-19:10 | 3 | Charge | 8637 | 12,909 | 33.0 | 26.5 | 22.7 | 32.1 | 03 | 300 | 555 | 0.00089 |
| 12/11/73 | 08:30-09:15 | 3 | Charge | 8724 | 13,026 | 34.1 | 26.2 | 24.1 | 32.0 | 03 | 300 | 555 | 0.00089 |
| | 09:15-09:30 | 3 | Hot Metal | 8724 | 12,927 | 34.1 | 26.4 | 23.9 | 31.8 | 03 | 300 | 555 | 0.00089 |
| | 09:30-12:15 | 3 | Lance | 8695 | 12,877 | 33.4 | 26.5 | 24.2 | 31.6 | 03 | 300 | 555 | 0.00089 |
| | 10:20-13:00 | 4 | Charge | 8737 | 12,852 | 33.2 | 26.5 | 24.1 | 31.3 | 03 | 300 | 555 | 0.00089 |
| | 13:00-13:20 | 4 | Hot Metal | 8753 | 12,894 | 33.1 | 26.4 | 24.7 | 30.9 | 03 | 300 | 555 | 0.00089 |
| | 13:10-16:05 | 3 | Charge | 8782 | 13,040 | 33.6 | 26.3 | 23.8 | 32.0 | 03 | 300 | 555 | 0.00089 |
| | 13:20-16:05 | 4 | Lance | 8782 | 13,040 | 33.6 | 26.3 | 23.8 | 32.0 | 03 | 300 | 555 | 0.00089 |

*Stopped Sampling at 16:30

APPENDIX C1

OPEN HEARTH FURNACE OPERATING SUMMARY

| Number * | Date | TIME | | | | | |
|---|---|---|---|---|---|---|---|
| | | Previous Heat Tapped | Began Charging | Finish Charging | Begin Hot Metal Addition | End Hot Metal Addition | Heat Tapped |
| 37770 | 12/05, 73 | 0830 | 0910 | 1010 | 1220 | 1235 | 1450 |
| 47657 | 12/05/73 | 0705 | 0745 | 1015 | 1050 | 1105 | 1340 |
| 37771 | 12/05/73 | 1450 | 1600 | 1815 | 1850 | 1900 | 2130 |
| 47658 | 12/05/73 | 1340 | 1420 | 1645 | 1715 | 1730 | 1916 |
| 37774 | 12/06/73 | 0840 | 1125 | 1400 | 1505 | 1515 | 1727 |
| 47661 | 12/06/73 | 0700 | 0740 | 1035 | 1120 | 1150 | 1341 |
| 37775 | 12/06/73 | 1727 | 1805 | 2020 | 2050 | 2100 | 2250 |
| 47662 | 12/06/73 | 1340 | 1420 | 1620 | 1715 | 1730 | 1934 |
| 37777 | 12/07/73 | 0500 | 0540 | 0740 | 0815 | 0830 | 1009 |
| 47665 | 12/07/73 | 0710 | 0750 | 1050 | 1115 | 1130 | 1305 |
| 37778 | 12/07/73 | 1010 | 1050 | 1245 | 1325 | 1355 | 1538 |
| 47666 | 12/07/73 | 1310 | 1430 | 1710 | 1750 | 1800 | 1944 |
| 37782 | 12/08/73 | 1010 | 1105 | 1255 | 1330 | 1345 | 1541 |
| 47669 | 12/08/73 | 0810 | 0850 | 1100 | 1210 | 1225 | 1350 |
| 37783 | 12/08/73 | 1540 | 1645 | 1915 | 1955 | 2005 | 2209 |
| 47670 | 12/08/73 | 1350 | 1430 | 1710 | 1745 | 1800 | 2007 |
| 37785 | 12/09/73 | 0335 | 0415 | 0625 | 0710 | 0725 | 0939 |
| 47673 | 12/09/73 | 0700 | 0740 | 0940 | 1005 | 1020 | 1219 |
| 37786 | 12/09/73 | 0940 | 1020 | 1240 | 1310 | 1320 | 1536 |
| 47674 | 12/09/73 | 1220 | 1300 | 1535 | 1610 | 1625 | 1819 |
| 37787 | 12/09/73 | 1535 | 1620 | 1805 | | | |
| 37789 | 12/10/73 | 0330 | 0610 | 0755 | 0830 | 0845 | 1104 |
| 47677 | 12/10/73 | 0630 | 0755 | 0930 | 1020 | 1035 | 1225 |
| 37790 | 12/10/73 | 1105 | 1145 | 1345 | 1430 | 1445 | 1640 |
| 47678 | 12/10/73 | 1225 | 1330 | 1625 | 1700 | 1720 | 1910 |
| 37791 | 12/10/73 | 1640 | 1720 | 1925 | 1945 | 2010 | 2210 |
| 37793 | 12/11/73 | 0425 | 0545 | 0840 | 0915 | 0930 | 1214 |
| 47681 | 12/11/73 | 0800 | 1020 | 1230 | 1300 | 1315 | 1602 |
| 37794 | 12/11/73 | 1215 | 1315 | 1600 | 1643 | 1700 | 1935 |

* The first digit identifies the furnace, the remaining four identify the batch number.

APPENDIX C2

OPEN HEARTH FURNACE MATERIALS SUMMARY

| Heat Number | Cold Iron Charge* | Steel Charge | Non Metallic Charge | Hot Metal Charge (Direct) | Extra Hot Metal Addition | Metallic Addition | Non Metallic Addition |
|---|---|---|---|---|---|---|---|
| 47657 | 38200 | 317100 | 27200 | 217000 | --------- | 9000 | -------- |
| 47658 | 40000 | 311300 | 28000 | 216500 | --------- | 5000 | -------- |
| 47661 | 0 | 314000 | 25200 | 258000 | --------- | 14100 | -------- |
| 47662 | 0 | 285800 | 27000 | 286000 | --------- | 11000 | -------- |
| 47665 | 49000 | 311800 | 20500 | 213900 | --------- | 8800 | -------- |
| 47666 | 42000 | 310300 | 23500 | 224200 | --------- | 5800 | -------- |
| 47669 | 34000 | 314200 | 23500 | 216700 | --------- | 7700 | -------- |
| 47670 | 34200 | 314200 | 22300 | 203000 | --------- | 15800 | -------- |
| 47673 | 0 | 314800 | 21700 | 261000 | --------- | 10800 | -------- |
| 47674 | 55000 | 314000 | 22300 | 201000 | --------- | 5000 | -------- |
| 47677 | 0 | 314800 | 23100 | 259900 | --------- | 5700 | -------- |
| 47678 | 54200 | 308100 | 23700 | 200000 | --------- | 7900 | -------- |
| 47681 | 25000 | 311400 | 23900 | 227900 | --------- | 8500 | 4500 |
| 37770 | 41200 | 319200 | 25200 | 212000 | 8000 | 13300 | -------- |
| 37771 | 58800 | 314800 | 25100 | 197800 | --------- | 13300 | -------- |
| 37774 | 0 | 286600 | 35400 | 283300 | --------- | 13100 | -------- |
| 37775 | 0 | 285100 | 21300 | 284700 | --------- | 5800 | -------- |
| 37777 | 35600 | 311000 | 24500 | 219200 | --------- | 6300 | 4000 |
| 37778 | 49000 | 310800 | 23500 | 212800 | --------- | 7600 | 4000 |
| 37782 | 24400 | 314800 | 22300 | 231800 | --------- | 7700 | -------- |
| 37783 | 54400 | 314000 | 21700 | 202000 | --------- | 7700 | -------- |
| 37785 | 0 | 315600 | 22900 | 258000 | --------- | 17000 | -------- |
| 37786 | 57000 | 314200 | 22500 | 202000 | --------- | 8100 | 4000 |
| 37787 | 67200 | 313400 | 20900 | 197000 | --------- | 14800 | 4500 |
| 37789 | 0 | 312200 | 22700 | 260900 | --------- | 15300 | 4000 |
| 37790 | 23000 | 314200 | 23500 | 234500 | --------- | 6200 | -------- |
| 37791 | 65300 | 316800 | 21900 | 196000 | --------- | 5000 | -------- |
| 37793 | 61000 | 314400 | 23900 | 199000 | 15000 | 11500 | -------- |
| 37794 | 35000 | 312800 | 23500 | 220000 | --------- | 13300 | -------- |

* All charges and additions are weights of material in pounds.

## APPENDIX D

## ESTIMATED OPERATING COSTS OF THE STEAM HYDRO AIR CLEANING SYSTEM

Data for these cost estimates were taken from Peters and Timmerhans, Plant Design and Economies For Chemical Engineers, 2nd edition, 1968 and are based on cost data for the year 1967.

| Steam | Cost |
|---|---|
| 500 PSIG | $0.60 - $1.20/1000 lb |
| 100 PSIG | 0.50 - 1.00/1000 lb |
| **Water** | |
| Well | 0.03 - 0.15/1000 gal |
| River | 0.02 - 0.06/1000 gal |
| Fuel Oil | 0.05 - 0.15/gal |

Figure D1 shows estimated energy requirements as furnished by Lone Star Steel for achieving various levels or grain loadings when operating on the open hearth process. Note that as the backdraft increases, the steam requirement increases. In the case of waste heat boilers - if these are not designed so that they can be kept clean, the steam requirement is higher than for a clean system. Attention is also invited to the fact that on installations such as cupolas and sinter

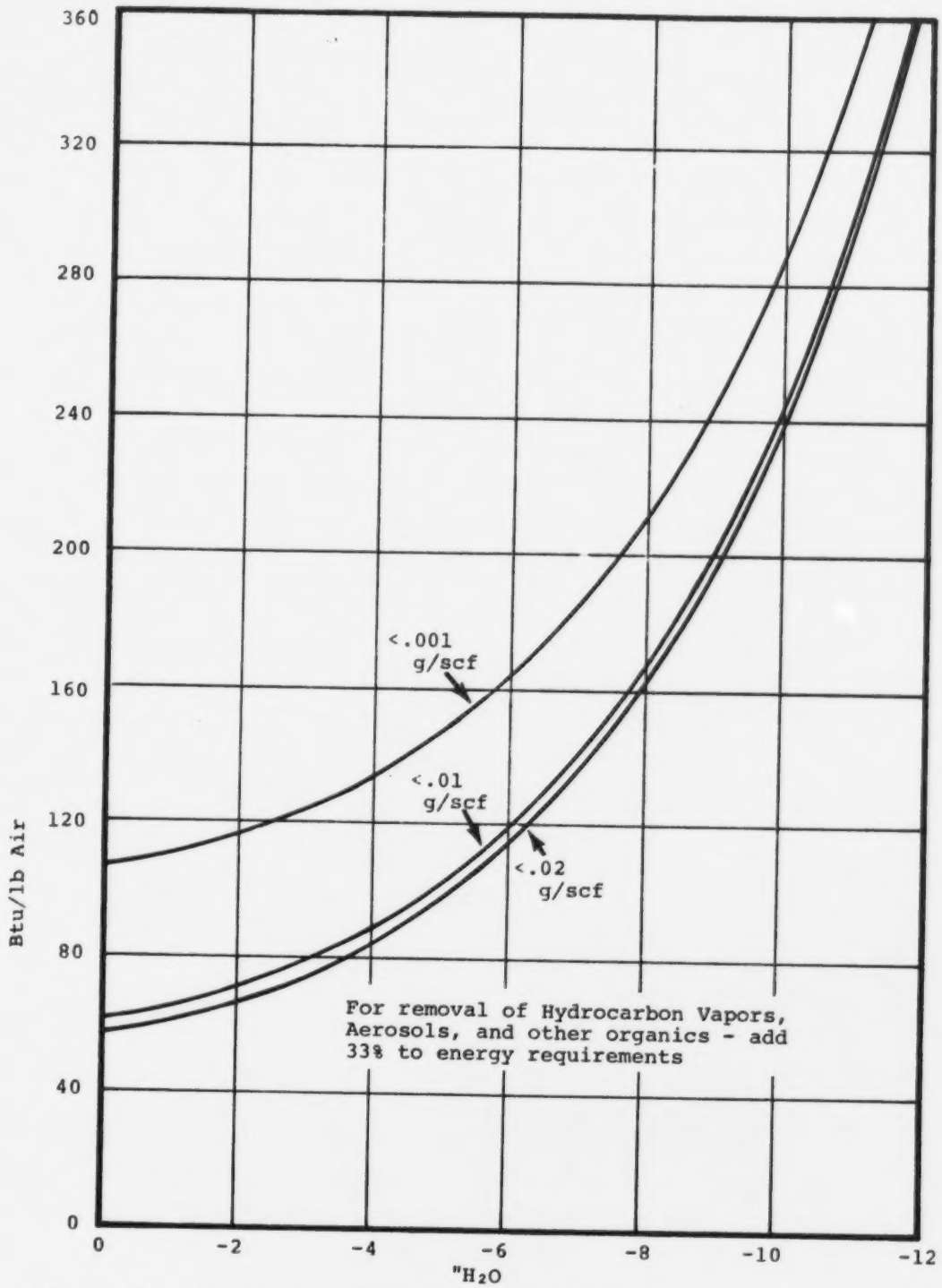


Figure D1. Steam Hydro Steam Requirements Necessary for Producing the Indicated Outlet Loadings When Handling Open Hearth Emissions.

plants, the energy to remove hydrocarbon vapors, aerosols, and other organics is approximately 1/3 higher than for the removal of inorganics, i.e., particulate. The level of cleaning can be readily changed by a change in the energy to the system. Once the Steam-Hydro is installed, capital costs are not involved in increasing the cleaning level, simply the operating costs. The operating costs described here are based on two conditions---one in which the system energy is derived solely from process waste heat and one for which fuel oil supplies the energy. These figures are estimates only and do not include such things as savings deriving from the fact that the system provides its own draft as well as that for the furnaces, consequently eliminating I.D. and F.D. fans, blowers, etc.

The conditions of the tests were:

Steam usage: 7300 lb/hr at 250 PSIG

Water usage: 61 gal/min (of which 55 gal/min is recovered)

Air flow: 13000 SCFM with a system back pressure of 6" $H_2O$.

Outlet particulate loading: 0.0007 gr/DSCR

Note that in this application the system back pressure was anomalously high as a result of fouling of the waste heat boiler which was installed with tube rappers but without soot blowers. Figure D1 indicates that this back pressure would lead to a 50% increase in the system energy requirements as compared to the requirements at a back pressure of 1 inch of water.

Assuming nominal values for costs of $0.85/1000 lb for steam (including the cost of fuel), 0.04/1000 gal for water, and 0.08/gal for fuel oil, the operating cost per thousand SCF when running with a back pressure of 6" W.G. are $0.007977 for steam production, which includes a fuel cost of $0.00671, and a water cost of $0.000188. With a system back pressure of 1" W.G. the steam cost is reduced to $0.00532 of which $0.00474 represents the cost of fuel. Thus where waste heat is available for steam production, eliminating the fuel cost, the operating cost per 1000 SCF are $0.00145 and $0.00077 respectively for operating at 6" W.G. and 1" W.G. back pressures. For applications where waste heat is not available for steam production and fuel must be supplied the costs rise to $0.00817 and $0.00551 per thousand SCF at the afore mentioned back pressures. For operation at 1" W.G. back pressure the annual operating costs per SCFM are $0.403 in the waste heat case and $2.89 for the case in which fuel must be purchased. For the purposes of the preceeding operating cost estimates amortization of capital costs were not included. Inclusion of capital cost amortization would result in substantial increases in the above figures.

## APPENDIX E

## TABLE OF CONVERSION FACTORS

| To Convert From | To | Multiply By |
|---|---|---|
| lbs | Kg | 0.454 |
| grains/cf | grains/$m^3$ | 2.288 |
| cfm | $m^3$/sec | 0.000472 |
| lbs/$in^2$ | Kg/$m^2$ | 703.1 |
| °F | °K | (°F + 460) x 5/9 |
| °R | °K | 0.556 |
| inches w.g. | mm Hg | 1.8682 |
| gallon | liter | 3.785 |
| Btu | Joules | 1054.8 |
| feet/min | m/sec | 0.00508 |

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before co

| | |
|---|---|
| 1. REPORT NO. EPA-650/2-74-028 | 2. PB 232 436 |
| 4. TITLE AND SUBTITLE Lone Star Steel Steam-Hydro Air Cleaning System Evaluation | 5. REPORT DATE April 1974<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) J. D. McCain and W. B. Smith, Southern Research Institute, Birmingham, Ala. 35205 | 8. PERFORMING ORGANIZATION REPORT NO. |
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16. ABSTRACT The report gives results of fractional and overall mass efficiency tests of the Lone Star Steel steam-hydro scrubber. The tests were performed on one of seven modules of a full scale scrubber used for controlling particulate emissions from an open hearth furnace. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 to 5 $\mu$m, and on the number basis for sizes smaller than about 1 $\mu$m using optical and diffusional methods. The report includes brief descriptions of the open hearth process, the Lone Star Steel steam-hydro scrubber, economics of operating the scrubber, measurement methods for calculating fractional efficiency, a synthesized time history of the open hearth particulate emissions, and fractional efficiencies as measured for several scrubber operating conditions.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Air Pollution<br>Economic Analysis<br>Soot<br>Scrubbers<br>Measurement<br>Openhearth Furnaces<br>Flue Dust | Air Pollution Control<br>Stationary Sources<br>Particulates<br>Steam-Hydro Scrubber | 13B, 14A<br>21B<br>07A<br><br>13A |

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